APPARATUS AND METHOD FOR PASSIVE ADAPTIVE FLYING HEIGHT CONTROL IN A DISC DRIVE

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Related Applications

This application claims the benefit of priority of United States Provisional Patent Application Serial No. 60/269,924 entitled "PASSIVE ADAPTIVE FH CONTROL FOR TPTR," filed February 19, 2001.

Field of the Invention

This application relates to magnetic disc drives and more particularly to a disc drive having shape memory alloys in an actuator arm suspension for providing passive control of the flying height of a read/write head.

Background of the Invention

Disc drives are data storage devices that store digital data in magnetic form on a rotating information storage disc. Modern disc drives comprise one or more rigid information storage discs that are coated with a magnetizable medium and mounted on the hub of a spindle motor for rotation at a constant high speed. Information is stored on the discs in a plurality of concentric circular tracks typically by an array of transducers or "heads" fixed to a slider mounted on a radial actuator arm for movement of the heads in an arc across the surface of the discs.

The actuator arms are driven by an actuator assembly located adjacent to the disc(s) in the disc drive. The actuator assembly includes a plurality of actuator arms. One or more suspensions are attached to the distal end of each actuator arm, where each suspension includes a rigid load beam for supporting each head of the disc drive above the disc. Suspensions are formed with a bend section that exerts a pre-load force on the head toward the disc.

Each of the concentric tracks is generally divided into a plurality of separately addressable data sectors. The recording transducer, e.g. a magnetoresistive read/write head or pole, is used to transfer data between a desired track and an external environment. During a write operation, data is written onto the disc track and during a read operation the head senses the data previously written on the disc track and transfers the information to a host computing system. The overall capacity of the disc drive to store information is dependent upon the disc

drive recording density. It is of particular importance in the disc drive art to maximize the disc drive recording density.

An important parameter affecting the recording density of a disc drive is the flying height of the head over the magnetizable medium layer of the information storage disc. The flying height of the head will vary depending upon several factors and thus a tolerance called the head/disc spacing budget is built into the actuator assembly. Smaller head/disc spacing budgets allow for closer spacing of the magnetic signals, *i.e.*, bits, recorded on the information storage disc, which in turn allows for narrower track widths and consequent greater recording densities on the drive. As such, one way to maximize the disc drive recording density is to minimize the head/disc spacing budget. However, there is at least the following major shortcoming with regard to minimizing the head/disc spacing budget.

Included in the head/disc spacing budget are factors such as disc roughness, lube and carbon thickness, thermal pole tip recession ("TPTR"), and part tolerances. Thus, in order to decrease the head/disc spacing budget, these factors must likewise be proportionately decreased or risk contact of the head with the disc surface thereby causing stiction and/or loss of data. Some factors, such as the disc roughness and material thickness can be scaled down as the spacing budget is decreased. However, other factors like TPTR cannot be scaled down. Thus, there is a need to minimize TPTR so that the head/disc spacing budget may be minimized.

TPTR occurs because the materials of the slider have different coefficients of thermal expansion than the materials of the transducer or head. As such, the materials of the slider expand and contract at different rates than the materials of the head with temperature changes. These different rates of expansion and contraction cause the head to protrude beyond the slider and move closer to the disc when the temperature increases, thereby decreasing the head flying height and risking contact with the disc. TPTR does cause some self-correction by changing the air bearing surface of the slider and thereby increasing the flying height. However, this self-correction is not sufficient to overcome TPTR.

One way to fully correct TPTR is to provide an active mechanism to modify flying height, such as an electric current. However, this type of active control requires precise measurement and/or monitoring of the TPTR. Further, such active controls add significant expense to the manufacturing costs. Against this backdrop the present invention has been developed.

Summary of the Invention

It is thus desirable to provide an apparatus for adapting flying height of a read/write head over a disc due to changes in temperature in a head disc assembly in a disc drive, which does not require any active control elements.

The head disc assembly has a base plate and a top cover which encloses a drive motor, a disc supported thereon, and an actuator assembly which transfers data to and from the disc. The actuator assembly has an actuator arm and a suspension having one end connected to a slider and an opposite end connected to the actuator arm. The slider carries the head. At least one shape memory alloy segment is attached to the suspension for moving the slider between a contracted state away from the disc when temperature within the head disc assembly increases and a relaxed state near the disc when temperature within the head disc assembly decreases.

These and various other features as well as advantages which characterize the present invention will be apparent from a reading of the following detailed description and a review of the associated drawings.

Brief Description of the Drawings

FIG. **1** is a plan view of a disc drive in accordance with a preferred embodiment of the invention.

FIG. **2** is an enlarged partial exploded view of a suspension with an attached slider, as shown in FIG. **1**, incorporating a preferred embodiment of the present invention.

FIG. **3** is a perspective view of the suspension of FIG. **2** in a relaxed state.

FIG. **4** is a perspective view of the suspension of FIG. **2** in a contracted state.

FIG. **5** is an exaggerated side view of the suspension of FIG. **3**.

FIG. **6** is an exaggerated side view of the suspension of FIG. **4**.

Detailed Description

A disc drive **100** constructed in accordance with a preferred embodiment of the present invention is shown in FIG. **1**. The disc drive **100** includes a base plate **102** to which various components of the disc drive **100** are mounted. A top cover **103** cooperates with the base **102** to form an internal, sealed environment for the disc drive in a conventional manner. The components include a disc drive spindle motor assembly which includes a spindle motor **104** that rotates one or more information storage discs **106** at a constant high speed. Information is

written to and read from tracks **108** on the discs **106** through the use of an actuator assembly **110** which rotates about a bearing shaft assembly **112** positioned adjacent the discs **106**. The actuator assembly **110** includes a plurality of actuator arms **114** which extend towards the discs **106**, and one or more suspensions or flexures **116** which extend from each of the actuator arms **114**. Mounted at the distal end of each of the suspensions **116** is a head (transducer) **118** that includes an air bearing slider **120** (FIG. **3**) enabling the head **118** to fly at a head flying height in close proximity above the corresponding surface of the associated information storage disc **106**.

The actuator arms **114** each attach a single suspension **116** for holding a slider **120** with a predetermined pre-load force against their respective discs **106**. In use, the actuator arms **114** are rotated by the voice coil motor **128** about its axis to move the sliders **120** over the surfaces of the discs **106**. Although several embodiments of the present invention are preferably described below with respect to use with a rotary voice coil motor, it is understood that the present invention may be used with any other actuator commonly utilized in disc drives.

Suspensions **116** must be accurately positioned over the discs with a predetermined pre-load force in the downward direction, *i.e.*, toward the disc **106**. Suspension pre-load forces are determined and employed so that the air bearing slider **120** will attain an optimal head flying height above the surface of the disc **106** under normal operating conditions. The optimal head flying height is determined by setting a head/disc spacing budget, which is determined by considering various factors including TPTR. As discussed previously, there is a need to minimize the head/disc spacing budget in order to maximize the disc drive recording density.

The air bearing slider **120** is typically formed from a block having a specially etched air bearing surface that forms an air cushion or "bearing" as the disc **106** rotates beneath the slider **120**. The hydrodynamic lifting force provided by the air bearing surface acts against a downward pre-load force provided by the suspension **116** to cause the slider **120** to lift off and "fly" a very small distance above the surface of the disc **106** as the disc **106** spins up to its operating speed. This distance is referred to as the slider **120** flying height. Although the flying height of the slider **120** is only a fraction of a micron, this thin film of air between the slider **120** and the disc **106** prevents damage to the fragile magnetic coating on the surface of the disc **106**.

The slider **120** has a leading edge **121**, a trailing edge **123**, an upper surface **122**, and a lower surface **124**. The slider **120** is typically made of a ceramic type material such as altec, but may be comprise other less expensive materials such as silicon. The head **118** is fixed within the lower surface **124** of the slider **120** near the leading edge **121**. The head **118** is made of a transducing material such as copper. The differences in the coefficients of thermal expansion of the materials of the head **118** and the slider **120** cause them to expand and contract at different rates as the temperature changes. As the temperature increases in the disc drive **100**, the head **118** expands faster than the slider **120** thereby causing the head **118** to protrude beyond the lower surface **124** of the slider **120**. This protrusion of the head **118** lowers the head flying height and increases the risk that the head will crash into the disc **106**. This thermal phenomenon is referred to as Thermal Tip Pole Recession ("TPTR").

The suspension **116** preferably includes a relatively stiff load beam **150** and a relatively flexible gimbal **160** for attaching the slider **120** to the suspension **116**. A first or proximal end **152** (shown in FIG. **3**) of the load beam **150** is attached to the actuator arm **114**. A second or distal end **154** of the load beam **150** opposite the actuator arm **114** is attached (such as by welding or by an adhesive) to the more flexible gimbal **160** which, in turn, is fixed to the slider **120**. A distal end of the gimbal **160** includes a cutout region defined by two parallel arms or flexure beams **162** and a cross beam **164** defining an attachment pad **166**. A tongue **156** of the load beam **150** typically protrudes within the cutout region of the gimbal **160** so that a dimple **158** (shown in FIGS. **5** and **6**) located on the bottom of the tongue **156** may contact the top surface **122** of the slider **120** to transfer the preload force directly to the slider **120**. The attachment pad **166** of the gimbal **160** is secured to the top surface **122** of the slider, such as by an adhesive, so that the flexure beams **162** provide a resilient connection between the slider **120** and the relatively stiff load beam **150**. The resilient connection provided by the gimbal **160** is important to allow the slider **120** to pitch and roll (i.e., "gimbal") while following the topography of the rotating disc **106**.

In a preferred embodiment of the present invention, at least one discrete segment **200** comprising a shape memory alloy ("SMA") is attached to the suspension **116** as shown in FIG. **3**. SMAs expand and contract based upon changes in temperature. Thus when the SMA contracts, it causes the suspension to deflect thereby changing the flying height of the slider **120**. In this way, the SMA segment **200** provides passive control of the flying height of the slider **120** when the temperature in the disc drive **100** changes.

Either one or a plurality of the segments **200** may be attached to the beams **162** by a number of methods including sputtering and use of epoxies or other adhesives. A multitude of different compositions of SMA may be used, including, but not limited to, the following: gold-cadmium, silver-cadmium, copper-aluminum-nickle, copper-tin, copper-zinc, copper-zinc-aluminum, indium-titanium, indium-thalium, iron-platinum, nickle-aluminum, iron-manganese-silicon, manganese-copper, and nickle-titanium. Further, each of the aforementioned SMAs may comprise different percentages of each component metal. Every SMA has a crystalline transition temperature that varies depending on the composition of the SMA. Preferably, the type of SMA should be chosen after taking into account the following non-exhaustive list of factors: the strength, flexibility, and thickness of the gimbal **120**, the coefficients of thermal expansion of the slider **120** and the head **118**, the desired crystalline transition temperature, and the desired number of the SMA segments **200**.

The ambient temperature in a disc drive **100** usually varies from room temperature to 160 degrees Fahrenheit or 70 degrees Celsius. Within this temperature range, the SMA segment **200** may occupy two different phases: martensite and austenite. The SMA segment **200** exists in the martensite phase when the ambient temperature is below its particular crystalline transition temperature. As the ambient temperature rises above the crystalline transition temperature, the SMA undergoes a phase change to the austenite phase. The phase change from martensite to austenite causes the SMA segment to contract. SMAs are unique in that any deformation of the material in the cool state (martensite) can be undone by taking it to the heated state (austenite).

FIGS. **3-6** show how the phase transition of the SMA segments **200** on the flexure beam **162** of the gimbal **160** adapt to overcome the TPTR caused by an increase in temperature in the disc drive. It should be noted that FIGS. **3-6** are substantially exaggerated to illustrate the changes in the present invention, which changes actually constitute a fraction of a micron. FIGS. **3** and **5** shows the present invention in the normal or cool (martensite) state. As shown in FIG. **5**, in the normal state the lower surface **124** of the slider **120** is angled relative to the disc **106** such that the leading edge **121** is closer to the disc than the trailing edge **123**. The head **118** barely protrudes beyond the lower surface **124** and flies above the disc at the head flying height illustrated by a double-headed arrow **170**.

FIGS. **4** and **6** show how the present invention adapts and compensates for TPTR when the ambient temperature in the disc drive **100** increases. As discussed above, an increase in temperature causes the head **118** to expand and protrude beyond the lower surface **124** of the

slider **120** thereby decreasing the head flying height and increasing the risk of contact between the head **118** and the disc **106**. However, as the temperature increases, the SMA segments **200** undergo the phase change from martensite to austenite and contract in length. The contraction of the segments **200** cause the flexure beams **162** to bend upward and away from the disc **106**. As the flexure beams **162** bend upward, they cause the connected cross beam **164** and bonding pad **166** to likewise bend upward. The bonding pad **166**, in turn, pulls the slider **120**, and thus the head **118**, upward and away from the disc, thereby increasing the head flying height. In this way, the SMA segments compensate for the expansion of the head **118** by increasing the slider **120** flying height, thereby maintaining substantially the same head flying height **170** even with presence of TPTR.

In a preferred embodiment of the present invention, five SMA segments **200** are positioned on each flexure beam **162** of the gimbal **160**. More preferably, each of the five SMA segments **200** on each flexure beam **162** has a different transition temperature. Even more preferably, the five SMA segments have the following transition temperatures: 40°, 50°, 55°, 60°, 65° Celcius (100°, 120°, 130°, 140°, and 150° degrees Fahrenheit), with the 40° segment **200** positioned adjacent the cross beam **164**. In order to obtain symmetry of deflection in the gimbal **160**, the different SMA segments **200** are preferably arranged in parallel order on each of the flexure beams **162**. However, it should be noted that the SMA segments **200** may be positioned anywhere on the flexure beams so long as they act to move the slider **120** and the head **118** away from the disc **106** when the temperature rises beyond the crystalline transition temperature. For example, the segments **200** may be positioned near the cross beam **164** or centered about the dimple **158**. Alternatively, multiple segments **200** may span the entire length of the flexure beams **162**, thereby allowing a very smooth transition as the temperature rises. As a general rule, the more segments **200** used, the more the gimbal **160** will bend when the temperature rises.

Further, multiple segments **200** of the same SMA may be used, or each segment may comprise a different SMA, or any variation thereof. In order to achieve a wider range of flying height compensation, it is preferable to use different SMAs with different crystalline transition temperatures. Further, use of multiple segments of multiple types of SMAs make the transition more smooth over a wide temperature range. In contrast, use of multiple SMA segments **200** having the same transition temperature will cause greater deflection of the gimbal over a more narrow range of temperatures.

In contrast to the TPTR solutions that utilize active flying height compensation, the adaptive nature of the SMAs allows for passive control of the flying height and does not require additional or active control elements, such as the application of electric current, to make the change.

Although the foregoing discusses a specific type of suspension, it is important to note that the present invention may be used with any type of suspension. For example, it may be used with a suspension where the gimbal is positioned on top of the load beam (opposite the disc) or in a suspension where the gimbal is integrated with the load beam.

In summary, a suspension (such as **116**) for adapting flying height of a read/write head (such as **118**) due to changes in temperature in a disc drive (such as **100**) comprises a load beam (such as **150**), a gimbal (such as **160**) positioned at one end of the load beam (such as **150**), a slider (such as **120**) attached to the gimbal (such as **160**), wherein the head (such as **118**) is fixed to the slider (such as **120**), and a shape memory alloy segment (such as **200**) attached to the gimbal (such as **160**). The shape memory alloy may comprise nickel-titanium. A distal end of the gimbal (such as **160**) has two parallel flexure beams (such as **162**) connected by a cross beam (such as **164**) and the cross beam (such as **164**) defines an attachment pad (such as **166**) that is secured to a top surface (**122**) of the slider (such as **120**). The gimbal (such as **160**) may be attached to a lower surface of the load beam (such as **150**), attached to an upper surface of the load beam (such as **150**), or integrated with the load beam (such as **150**).

The suspension (such as **116**) may have second shape memory alloy segment (such as **200**), a plurality of additional shape memory alloy segments (such as **200**), or nine additional shape memory alloy segments (such as **200**) attached to the gimbal (such as **160**), wherein equal numbers of shape memory alloy segments (such as **200**) are attached to each of the flexure beams (such as **162**) of the gimbal (such as **160**). The SMA segments (such as **200**) may substantially span the entire length of the flexure beams (such as **162**) or be positioned near the cross beam (such as **164**) of the gimbal (such as **160**). The shape memory alloy segments (such as **200**) on each of the flexure beams (such as **162**) may have different transition temperatures.

A disc drive (such as **100**) has a base plate (such as **102**) and a top cover (such as **103**) enclosing a drive motor (such as **104**) carrying a disc (such as **106**) and an actuator assembly (such as **110**) having an actuator arm (such as **114**), a suspension (such as **116**) having one end connected to the slider (such as **120**) and an opposite end connected to the actuator arm (such

as **114**), and at least one shape memory alloy segment (such as **200**) attached to the suspension (such as **116**). The shape memory alloy segment (such as **200**) moves the slider (such as **120**) between a contracted state away from the disc (such as **106**) when temperature within the head disc assembly increases and a relaxed state near the disc (such as **106**) when temperature within the head disc assembly decreases.

The disc drive (such as **100**) may have at least three shape memory alloy segments (such as **200**) attached to opposite sides of the gimbal (such as **160**). Each of the segments (such as **200**) on each side of the gimbal (such as **160**) may be composed of a different shape memory alloy. All of the shape memory alloy segments (such as **200**) may be composed of at least two different shape memory alloys. Each of the segments (such as **200**) on each side of the gimbal (such as **160**) may have a different transition temperature.

The load beam (such as **150**) has a proximal end (such as **152**) and a distal end (such as **154**), wherein the proximal end (such as **152**) is attached to the actuator arm (such as **114**), and the distal end (such as **154**) forms a tongue (such as **156**) having a dimple (such as **158**) formed in a lower surface of the tongue (such as **156**) for transferring a preload force to the slider (such as **120**). The gimbal (such as **160**) is positioned near the distal end (such as **154**) of the load beam (such as **150**) with one end of the gimbal (such as **160**) forming a cutout region bordered by two side arms (such as **162**) and a cross beam (such as **164**). The cross beam (such as **164**) defines an attachment pad (such as **166**) attached to the slider (such as **120**). The dimple (such as **158**) of the load beam (such as **150**) protrudes through the cutout region to make contact with the slider (such as **120**) and to permit the slider (such as **120**) to pivot about the dimple (such as **158**). The shape memory alloy segments (such as **200**) may be centered about the dimple (such as **158**).

It will be clear that the present invention is well adapted to attain the ends and advantages mentioned as well as those inherent therein. While a presently preferred embodiment has been described for purposes of this disclosure, numerous changes may be made which will readily suggest themselves to those skilled in the art and which are encompassed in the spirit of the invention disclosed and as defined in the appended claims.